Transferred Substrate Heterojunction Bipolar Transistors For Millimeter And Submillimeter Wave Applications

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Introduction

- At JPL we are presently developing advanced Indium Phosphide Heterojunction Bipolar Transistors (InP HBTs) in a low parasitic process with the goal of producing the world's fastest transistors.

- Development of this technology will enable the next generation of advanced RF electronic systems.

- Systems will be capable of operating at higher frequencies, bandwidths, and provide performance beyond what is currently achievable.

Approach

- InP HBTs are one of the most prevalent high performance transistor technologies in use.

- HBTs have achieved a higher level of integration that High Electron Mobility Transistors (HEMTs) due to more uniform and reproducible microfabrication processes applicable to its structure.

- The method of Transferred Substrate was first demonstrated by Prof. Mark Rodwell of UCSB in producing HBTs with extrapolated power cutoff frequency (F_{max}) of 1080 GHz - highest reported in the world - better than HEMTs.

Approach

- JPL’s approach is to incorporate the Transferred Substrate process with aggressive lateral scaling with our advanced electron beam lithography system to produce the highest performance transistors.

- Yield and reliability, manufacturability, will be given consideration for a feasible solution.

- With the availability of advanced Transferred Substrate InP HBTs (TSHBT), we will develop ultra-high-speed components that could have a big impact on space and Earth instruments.

Background

- The figure of merits of high speed transistors are the current gain cutoff frequency (F_t) and maximum frequency of oscillation (F_{max}).

$$F_t = 1/(2 \cdot \pi \cdot \tau_{ec})$$

τ_{ec} is the total emitter to collector delay time of the HBT.

$$F_{max} \geq (F_t/(8 \cdot \pi \cdot R_b \cdot C_{cb}))^{1/2}$$

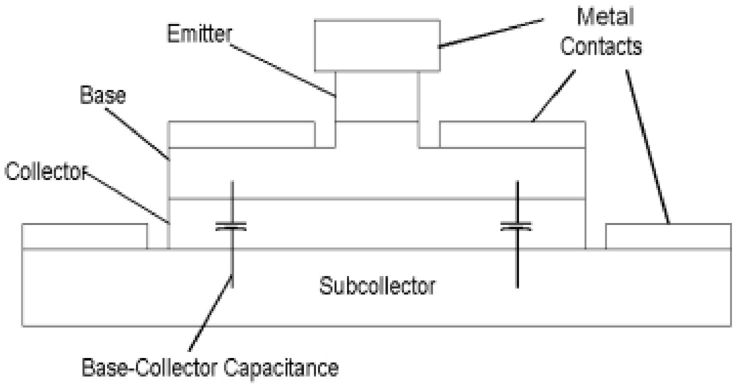
R_b is the HBT base resistance,

C_{cb} is the base to collector capacitance.

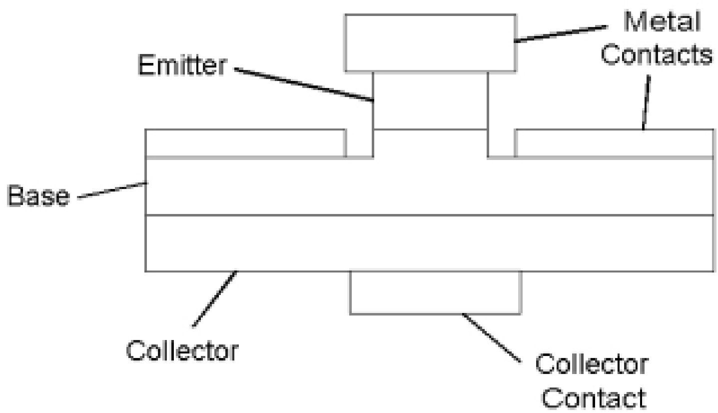
Background

- Transferred Substrate method for improving F_t and F_{max}
  - Standard mesa HBTs have a large base-collector overlap.
  - TSHBT process reduces the amount of overlap because the collector contact is defined on the backside of the wafer.
  - Minimizing base-collector overlap reduces C_{cb}, increasing F_{max}.
  - To improve F_t and F_{max} simultaneously, TSHBTs need to be scaled vertically to reduce the distance electrons need to travel and thus τ_{ec}, also the base needs to be doped as high as possible to decrease R_b.

Mesa HBT



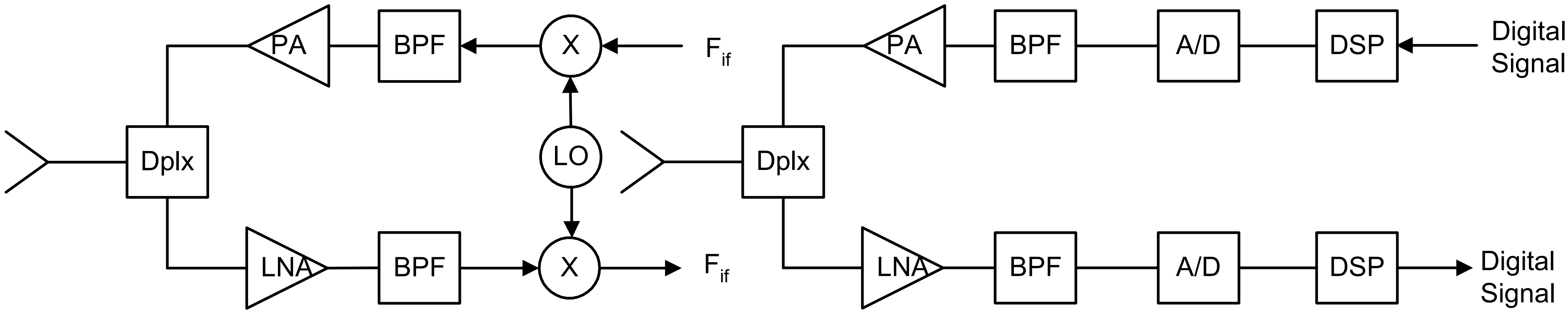
Transferred Substrate HBT



Applications

- Transferred Substrate HBTs could make a big impact in signal processing and communications.
  - Ultra-high speed components can be realized: low noise amplifiers, power amplifiers, analog to digital converters, flip-flops, multipliers, accumulators, etc. We envision +500 GHz amplifiers, +100 GHz digital ICs.

GHz Communications

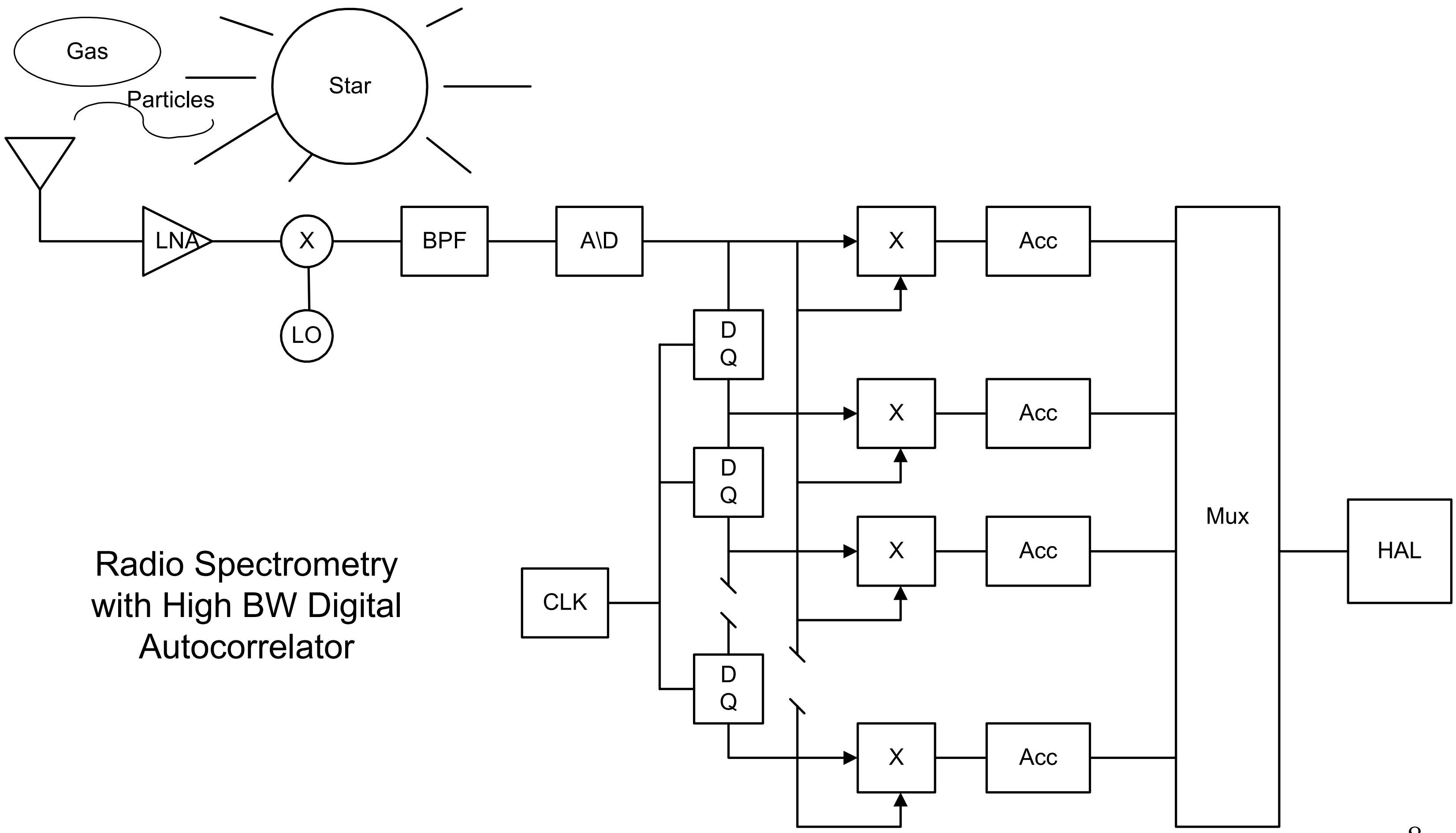


Components can be used to enhance transceiver front ends.

Ultra-high speed components can be used for future all digital transceivers.

Applications

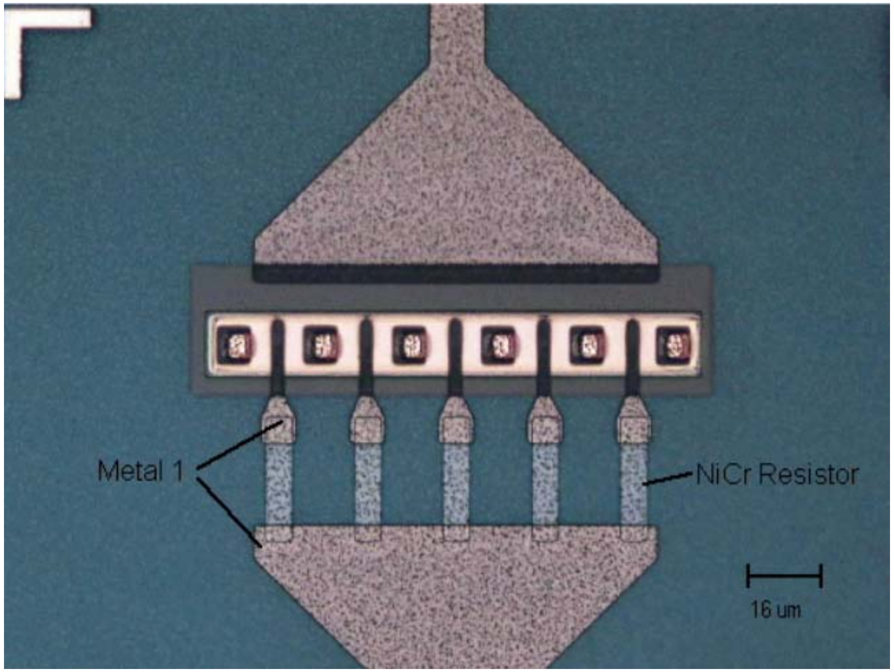
GHz Autocorrelators



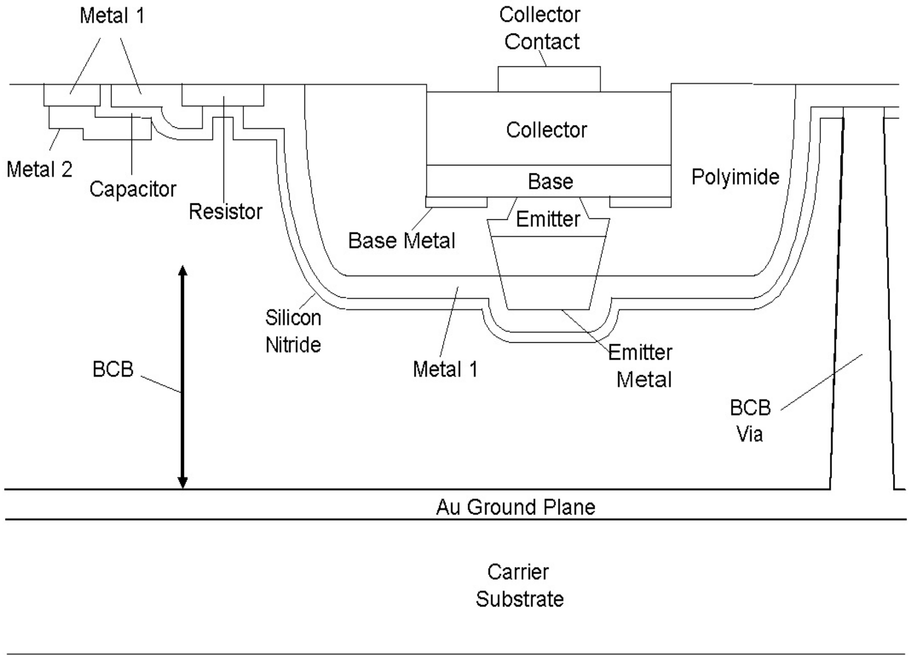
Radio Spectrometry
with High BW Digital
Autocorrelator

Development of TSHBTs at JPL

- JPL is in the process of completing the first set of TSHBTs.



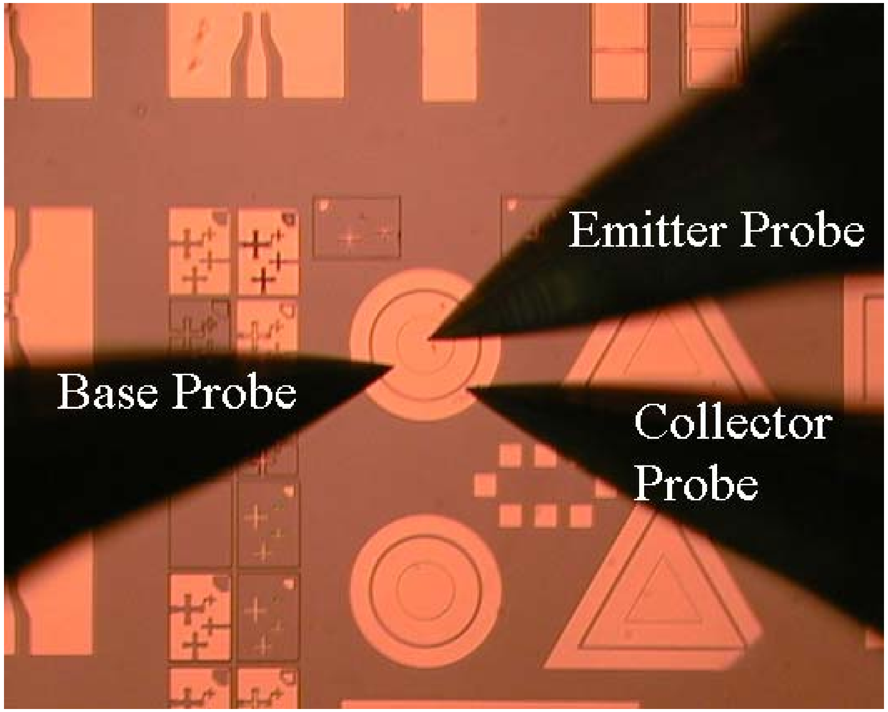
Optical photo of a TSHBT with ballasting resistors in fabrication.



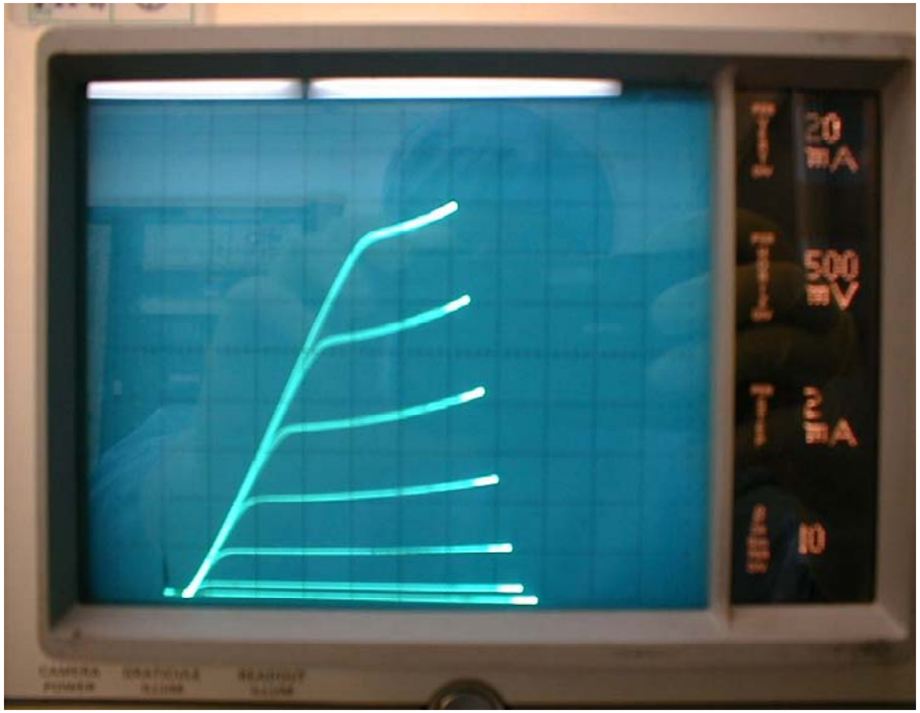
Schematic cross section of a TSHBT device with integrated resistors and capacitors.

Development of TSHBTs at JPL

- Identifying good and improving epitaxial material is critical.



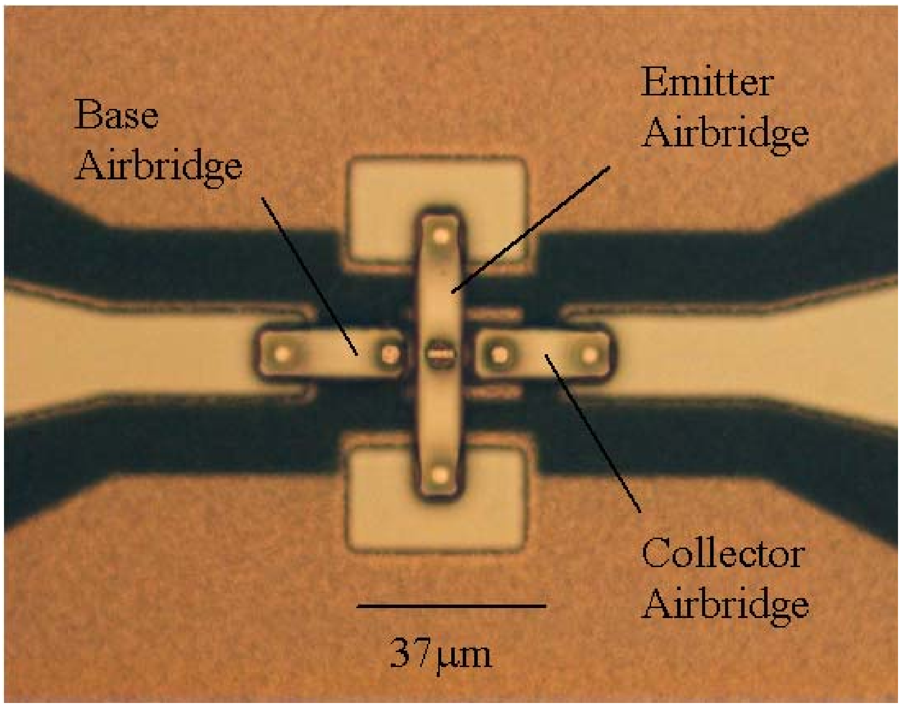
Large circular 10,000 μm^2 emitter area mesa HBTs are used to screen and optimize epitaxial material.



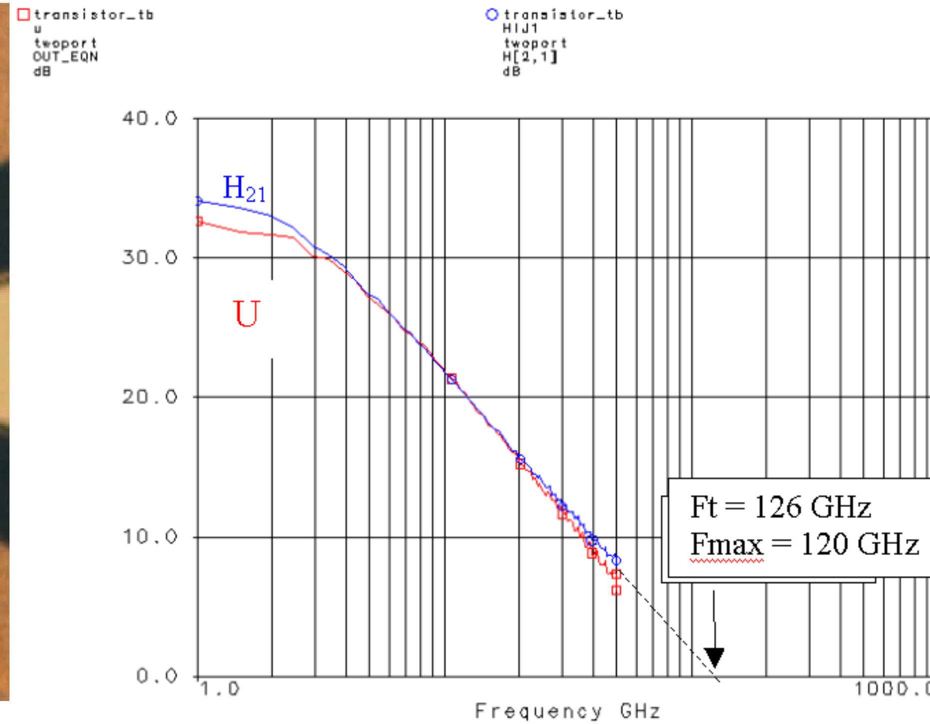
I_c vs. V_{ce} for different base currents of large mesa HBTs. Here β_{ac} = 15 to 20, and β_{dc} = 10 to 12.

Development of TSHBTs at JPL

- Proving out process steps towards TSHBTs is important.



RF mesa HBTs are used to test top side process steps for the TSHBTs and also RF material quality.



Gain plots of RF HBTs deduced from S-parameter measurements. Emitter current density is 62 kA/cm^2.

Summary

- JPL is developing advanced Transferred Substrate InP HBTs for the next generation of high performance electronic components.
- These components could enable ultra-high speed signal processing and communications, and make a large impact in future space and Earth systems.
- JPL is in the process of completing its first set of TSHBTs.
- JPL has already demonstrated a 2 μm contact lithography RF HBT process, towards developing the TSHBT process.
- JPL has developed a reduced process time and step, large sized HBT process for verifying and improving epitaxial material quality.

Acknowledgements

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